A Generic EXCEL-based Model for Computation of the Projected Levelized Unit Electricity Cost (LUEC) from Generation IV Reactor Systems

Economic Modeling Working Group (EMWG)
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I. Introduction

One of the FY04 tasks for the EMWG is the production of a model description and sample case for a LUEC model that conforms with the assumptions and algorithms described in the revised *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems.* This model must be sufficiently "generic" in the sense that it can accept the types of projected input performance and cost data that is expected to become available from Gen IV concept development teams over the next few years. It also should be suitable for international use, i.e. the economic algorithms therein should not include taxation rules and other economic practices that are practiced only in the U.S.

It was decided to utilize EXCEL initially because of the availability of this software (even internationally) and the ease with which generic cost modules or worksheets can be connected to external, concept-specific models such as cost/size scaling relationships. It is realized that as the EMWG moves toward consideration of systems with multiple fuel recycle, the computational limitations of EXCEL may force the EMWG to move toward other software options such as PC-based FORTRAN.

II. Modeling Goals

The goals of the model (and *Guidelines*) development effort were the following:

1.) Simplicity. Over half of the Generation IV systems concepts are in the very early R&D stages. This implies that the systems definition and the amount of cost data available thereon will be relatively small compared to Generation II, III, or III+ systems. This means that complex economic models, such as those used by USCEA, investment banks, universities (such as the recent U. of Chicago Competitiveness Study) and non-governmental organizations (NGOs) used to assess the competitiveness of near-term nuclear technologies against other energy choices (natural gas, coal, etc.), are not "simple" enough for this task. (Many of these larger models require the input of complex year-by-year cost and revenue data, schedules, fuel loading patterns, depreciation tables and other information that is not expected to available for several years for Generation IV system, and that are also specific only to U.S. economic conditions.
2.) Universality. One of the goals for Generation IV systems is that they be good candidates for deployment in both the developed countries and the developing world. Since tax structures, discount rates, labor costs, regulation, financing

methods, etc are different than in the U.S., the EMWG must use a simple means for adjustment of the model.

3.) Transparency: The algorithms must sufficiently visible such that the user can understand how a particular value was derived. The use EXCEL software makes this readily possible.

4.) Adaptability and "Linkability": It should be possible to link various parts of the model to algorithms or data specific to a particular Gen IV concept. For example a "hard-wired" value for the cost of a particular subsystem at the 2-digit code of accounts level might be replaced by a link to a cost-scaling model which relates the cost of this system to the reactor size or other variables. Such "linkability" also makes the model available as an economic module for design optimization studies and for the application of EXCEL-friendly commercial uncertainty/risk analysis software such as @ Risk or Crystal-Ball.

III. Simplifications Utilized in Model

The following simplifications are built into the model:

1.) There is no need to enter as data or generate as output extensive tables of cash flows, material balances, or schedule linked data. This feature makes it possible to effectively link this LUEC model to design optimization and cost-scaling models specific to each Gen IV concept.

2.) All data is input, manipulated, and generated in constant $, thus avoiding the need to deal with escalation tables.

3.) The same discount rate is used for construction financing, capital amortization, and D&D escrow fund accumulation. Judicious selection of the real discount rate can be used to account for socioeconomic factors such as taxation, financing risk, market risk, government versus private ownership, national investment policy, etc.

4.) The reactor system "life cycle" is essentially broken into two parts: a design/construction/start-up/financing phase for which a "total capitalized cost" is calculated; and a multi-year "operational" phase over which electricity is generated, the "capitalized cost" amortized, the D&D costs escrowed, and operational costs such as staff, fuel, waste disposal, maintenance, upgrades, regulation costs, and other consumables expensed. All costs over this operational period are levelized in constant dollars such that their values remain the same over the economic (operational) life of the facility. It is realized that in reality even constant dollar costs can vary from year to year; however, since this model is to be used for technology comparison purposes rather than cash flow projection and planning, its simplicity is an asset rather than a shortcoming.

5.) The fuel cycle model as presently constructed is for a once-through system without recycle. No iterative loops are built in to allow closure of multiple recycle material balances. Other fuel cycle simplifications are as follows:
    a. Only two types of fuel can be defined: the initial core fuel and the reload fuel. These two fuels can have different fissile enrichments.
    b. The costs of fuel cycle services are the same in constant dollars for the life of the facility. Again, this is a gross simplification; however, again, we

want to compare reactors systems economics for a given set of fuel cycle economics.

c. No material losses are assumed between fuel cycle steps. No spare fuel assemblies are assumed to be purchased.
d. The timing (lag and lead times) of fuel cycle service purchasing is not treated in this model as it is in the OECD/NEA, USCEA, and other more complex models. This allows avoiding consideration of year-by-year data and its modeling complexities.
e. Even if fuel cycles with other than annual refuelings are used, the fuel costs are ultimately adjusted to annual average values by the model.
f. Spent fuel disposal costs are treated on a mills-per-kilowatt basis. For non-U.S. nations it will be necessary to convert units such as $/kgHM for spent fuel disposal to mills/kwh or $/MWh.
g. The initial core is included in the total capitalized cost, hence it is assumed to be amortized along with the other reactor front-end costs. This differs from typical U.S. modeling practice; however, it may address the reality that a developing country would have to finance this very significant cost along with the reactor itself.

6.) The design/construction/start-up total duration must be an integer number of years.
7.) The annual power production and capacity factor for the system are the same over the duration of the plant life.
8.) The amortization life of the plant is the same as its operational life.
9.) The output LUEC has four calculated components: capital recovery, fuel, operational, and D&D escrow fund costs. Each of these is calculated in constant dollars and is the same over the operational life of the plant.

IV. Worksheet Tab: "Input Data"

The items on this worksheet highlighted in blue background in the EXCEL page Figure 1 below are the principal non-capital cost inputs to the model. Each is described below:

DATA TO BE PROVIDED BY DESIGNER/PROPONENT

"Plant description"**—**This set of alphameric characters describes the name of the reactor and any other word descriptors. **Because of the availability of data a non-Gen IV reactor is used for an example.** A Gen III ABB-CE (now Westinghouse) System 80+ PWR is the system described.

"Site size"—This input tells the capital cost module the size in acres of a reactor site where new land must be purchased. The line below shows the conversion of this value to metric units, i.e. hectares. For the example the site size is set as zero, since it is assumed the System 80+ reactor is built on an existing reactor site.

"Reactor net capacity"—This is the design **electrical** production capacity of the reactor after internal loads, such as "house power" to drive pumps, etc. is subtracted from the gross power. If thermal power is needed, it would be necessary to divide the gross electrical capacity by the thermodynamic efficiency. Since this particular example model is oriented toward electricity production, neither the thermodynamic efficiency or gross power are utilized. (To adapt this model for thermal production of hydrogen, these variables would need to be added, which should be a simple modification.) This capacity is assumed to remain the same over all the reactor's operating years.

"Reactor Capacity Factor"—This factor is used to calculate the actual number of kilowatt-hours produced in a year and accounts for the fact that over time the reactor does not operate 365.25 days per year. This factor accounts for the planned and unplanned outages and represents the projected long term reactor performance over its operational life. This factor has a very significant effect on the economics due to the fact that it factors into the "production" or "performance" denominator term of the "unit cost" (cost per unit of production) figure of merit. The 80% value used for the System 80+ is very conservative in light of today's 90%+ capacity factor experience for many existing reactors. It should be kept in mind, however, that most reactors don't start out at high capacity factors, and that high values are realized only after years of operating experience.

"Plant economic and operational life"**—**For the simplified model this term represents both the expected regulatory and operational life of the plant and and also the time for recovery (amortization) of the capital cost. By setting these lifetimes equal, levelized constant dollar components of the LUEC can be calculated. 40 years is used for this case and represents what the USNRC would allow today with relicensing.

“Years to design/construct/start-up”—This integer value represents the total number of years from the decision to proceed with the project to completion of hot start-up (i.e.just prior to commercial operation.) The six lines below this allow the user to specify the shape (cumulative spending) of the spending profile and what percentage of the “overnight” capital cost is spent each year up to commercial operation. Presently a maximum of 5 years is allowed. In light of U.S. Gen II and III experience this maximum may seem too low; however, Gen IV systems should have improved constructability and licensability which should allow values less than 5 years. The example cumulative spending profile has the S-curve shape that is typical of large capital projects. This spending curve’s shape is important in calculation of construction financing (interest during construction) costs.

NON-FUEL DATA FROM EMWG (OR POSSIBLY DESIGNER)

“Cost per acre for land”—This is required by the capital cost module for a reactor on a new or “Greenfield” site. Since the example case is for an existing site, this value is not used here.

“Average craft labor rate”—This hourly rate is another input to the capital cost part of the model. In order for this value to be used, the direct capital cost (20 series of 2-digit EMWG code of accounts) must be broken down into its labor, materials, and equipment constituents. The labor terms is calculated by multiplying the labor-hours times the average “burdened” labor rate. “Burdened” means that the labor rate includes all overheads such as benefits, social insurance, etc. Since the System 80+ data is not broken down at this level of detail, the U.S. average value of $32/hr is not actually used for this example.

“Financial environment”**—**This alphameric work descriptor forms the basis for the selected discount rate. The user should state the regulatory, ownership, and financial risk environment for the reactor system. The example problem assumes the System 80+ system is constructed under the older U.S. regulated utility model with a guaranteed market for the power generated. For simplicity and “universality” no taxes are assumed.

“Real discount rate”—The real discount rate does not have an inflation component and should be selected based on the risk descriptor. Government financed projects will carry low discount rates. Regulated utility projects will have medium discount rates. Higher risk ‘merchant” facilities without guaranteed markets or guaranteed loans will carry high discount rates. (Suggested values are not included in this discussion since the country of choice also is a major factor in discount rate selection.) It should be noted that the discount rate can also be used to simulate (as a surrogate for) the effects of taxation, insurance, and other socioeconomic policy. The 5% real discount factor chosen for the example is on the low side for the U.S. and is a value selected by the EMWG for low risk projects. This rate is used both for calculation of interest during construction, loan amortization (capital recovery), and accumulation of a D&D escrow fund.

"Estimated D&D Cost"—This is the projected cost, including contingency but excluding interest, to decontaminate and decommission the nuclear plant. In this example case the $300 in constant $ includes removing and dispositioning the highly radioactive components, but leaving the reactor building. This value forms the "goal" amount for the escrow account accumulated during the operating years by use of a sinking fund with an interest (discount) rate the same as above. This value will vary by plant size and technology. Sometimes the D&D cost is calculated by assuming a fixed fraction of the reactor overnight cost.

FUEL DATA FROM DESIGNER

"Fuel Cycle Type"**—**This word descriptor is used to indicate the type of fuel cycle to be costed. For this example we are considering a once-through conventional LWR fuel cycle

The next three lines repeat data from above. The term "unadjusted" in front of the capacity factor indicates that no "performance" contingency or penalty has yet been applied.

"Fuel Material"—This word descriptor indicates the type of fuel. It does not fix the numerical values below it and is an alphanumeric heading only. The fuel described is typical zirc-clad LEUO2 pelletized PWR fuel in an ABB designed fuel assembly.

"U-235 enrichment level (1st core average)"—This value is typed in as a mass fraction U-235 and the program converts it to a percent. This value is the average fissile U-235 content of the first core uranium before irradiation. It is realized that commercial reactors often have several enrichments within their core; however, for simplicity and the fact that early Gen IV definitions/calculations are likely to deal with only one enrichment, the use of an average enrichment is specified. (The example LEUO2 initial core fuel for the System 80+ has an average enrichment of 2.64% U-235.)

"U-235 enrichment level (reload average)"-- This value is type in as a mass fraction U-235 and the program converts it to a percent. This value is the average pre-irradiation fissile U-235 content of the uranium fuel reloads inserted during periodic refuelings. It is realized that commercial reactors often have several enrichments within reloads; however, for simplicity and the fact that early Gen IV definitions/calculations are likely to deal with only one enrichment, the use of an average enrichment is specified. It should be noted that the total mass of a reload core is often a fraction of the mass of the initial core load. (The example LEUO2 reload fuel for the System 80+ in this case has an average enrichment of 3.78% U-235.)

“Heavy metal mass of a fuel assembly”—This value is the mass in kilograms of the fertile and fissile elements (heavy metal) in a typical fuel assembly. This value does not include the mass of any grids, spacers, cladding, or other hardware. If the fuel assembly consists of compounds of U or Pu (such as oxides) the mass is still to be expressed in terms of elemental heavy metal.

“Fuel Assemblies in a Full Core”—This integer value represents the number of fuel assemblies which comprise the entire reactor core, thus it is also the number of fuel assemblies in the initial core. For the System 80+ example there are 241 LEUO2 assemblies.

“Fuel Assemblies per Reload”—Since fuel is often left in the reactor for more than one cycle, it is usually not necessary to replace the entire core at each refueling. Usually a fraction of the core is replaced. This integer value gives the number of fresh, unirradiated assemblies introduced into the reactor at the beginning of each cycle. The initial core assemblies are not counted here. For the System 80+ 107 reload assemblies are inserted at each refueling.

“Average time between refuelings”—This value in years is the “cycle time” or time between refuelings. This value is used to calculate the amount of reload fuel needed over the plant operational life. For the System 80+ a 1.5 year (18-month) cycle is assumed. As higher burnup fuels are implemented, the cycle time may increase.

EMWG FUEL DATA: This data is predominantly economic data which may ultimately be defined by the EMWG. For reasons of simplicity, transportation costs, which are comparatively very small, are not separately calculated. The user should include the transportation of the product from each step to the next step in the price.

“Enrichment plant tails assay”--The economics of the front end of the fuel cycle is determined in large part by the balance between purchase of uranium ore and the purchase of uranium enrichment units (separative work or “SWUs”). Setting the transactional enrichment plant tails assay (the U-235 content of the depleted-U stream from the enrichment plant) at the right value can optimize the sum of the ore, conversion, and enrichment costs. The tails assay must be a value below U-235’s natural abundance of 0.711% U-235 and should be input as a mass fraction. For the example case a value of 0.003 is selected, which the program converts to 0.3%U-235.

“Enrichment plant feed assay”**—**This value defines the U-235 content of the UF6 fed to the enrichment plant. In most cases the material will be “natural” feed at 0.711% U-235. The value is input as a fraction (.00711) and is converted to a percentage by the program. There may be some cases where it is economically advantageous to feed high assay tails (0.4% U-235 or above) or low assay LEU from reprocessed U (0.9% U-235 or above).

“Price of uranium ore”—This value is the price of mined and milled/extracted “yellowcake” or U3O8 in dollars per pound (as it is expressed in the U.S.) The program will convert this value to metric units ($/kgU). For the example problem a price of $12/lb U3O8 is assumed.

“Price of U3O8 to UF6 conversion”—This value is the commercial price of chemically fluorinating U3O8 to the volatile UF6 form needed for uranium enrichment. It is normally expressed in $/kgU and is to be input in that form. For the example problem a price of $6/kgU is assumed.

“Price of enrichment”—This is the assumed price per SWU or “separative” work unit from a commercial enricher. The required SWUs are calculated from the fissile fuel enrichments (first core and reload) and the feed and tails U-235 assays above. The price is expressed in $/SWU or $/kgSWU. Note that for enrichments above 20% U-235 (Highly enriched uranium or “HEU”) there may be a price surcharge to cover the additional security and safety requirements for handling UF6 at such assays where criticality and non-proliferation concerns become important. For the example problem a SWU price of $100/SWU is assumed.

“Price of enrichment plant tails conversion/disposition”—In some nations it will no longer be permissible to store DUF6 enrichment plant tails cylinders on site. This is because of the long-term cylinder degradation problem and the possibility of toxic/radioactivity releases. This value is the price of converting the “tails” DUF6 to a stable chemical form such as an oxide, packaging it, shipping it, and burying it in a mine or shallow disposal area. The price for this step is to be expressed in $/kgU for the amount of DUF6 fed to such facilities. Since this step is not yet commercially available in the U.S., a value of $0/kgU is assumed.

“Price of fuel fabrication”—This price is for the production of finished fuel assemblies from the enriched UF6 product from the enrichment plant. This value is very specific to the type of reactor system evaluated. For the System 80+ PWR a value of $180/kgU or $180/kgHM (heavy metal) is assumed.

“Price of ‘once-through’ geologic waste (spent fuel) disposal”—For the U.S. this price is charged on a per kilowatt-hour produced basis. Based on Government mandate, the present price is 1 mill/kwh or $1/Mwh. At present this cost in the U.S. is not specific as to the type of reactor.

“Price of Reprocessing”—This input location is provided for future use. Presently this price is not used, since the System 80+ model is for a “once-through” cycle only; thus the 0 value.

“Contingency on fuel cost”—This value is the % additional cost added to the overall $/kgU or $/kgHM cost to account for uncertainties or risk. Since LWR fuel costs are based on commercial input prices, a 0% contingency is appropriate here.

NON-FUEL OPERATIONAL RECURRING COSTS: These 12 categories are the basic components for the annual costs of reactor non-fuel operational and maintenance (O&M) costs. They are inputs for costs likely to be encountered for any type of reactor. Some of these categories may ultimately come from another model or set of algorithms, e.g. staffing head count and amounts and unit costs of consumables such as "house" power and chemicals. These input costs are transferred to the "Operations and Decommissioning" worksheet where they are summed an the contribution to the cost of electricity calculated. The values shown for the System 80+ in the example are typical of a U.S. PWR. All of these values are input in millions of US$ per year. The contents of each category are shown below and conform to the EMWG Code-of-Accounts

- On-site staffing: Base Full time-equivalent person count for on-site staff. Costs for base salaries
- Pensions and benefits: These are personnel costs in addition to the base salaries, and may vary considerable country-by-country
- Consumables: These are operational and maintenance materials and commodities required to operate the plant, i.e. special chemicals, fuels (other than nuclear), off-site power, special clothing, lubricants, etc.
- Repair costs: Cost for special equipment items needed for repairs. Manpower costs for repairs are under staffing.
- Charges on working capital: These are interest charges for cash required to operate plant. This is a U.S. accounting category, and for this type of model probably should not be used.
- Purchased services and contracts: Many utilities worldwide utilize subcontractors for special maintenance or repair tasks and for refuelings. This category would also cover any special consultants utilized.
- Insurance premiums and taxes: Insurance costs could include commercial and government-provided insurance premiums. Taxes would vary from location to location. (These two items can also be covered by using a higher discount rate to account for these "social" costs.)
- Regulatory fees: Regulatory fees would include the costs of inspections and maintenance of required permits.
- Radioactive waste management: These costs are mainly those to dispose of contaminated maintenance equipment and process chemicals such as resins.
- Other general and administrative (G&A): These are "overhead" costs and vary from utility to utility, depending on accounting systems. These charges sometimes support utility "home-office"activities related to operations.
- Capital replacements: These are large equipment items such as steam generators which must periodically be replaced over the life of the plant. Normally capital funds would be used to do this.

For this model the costs of anticipated large items should be lumped and then spread over the operational life of the plant, i.e. "levelized".

- Contingency on non-fuel O&M costs: This contingency is the amount added to the total non-fuel O&M costs to cover uncertainties. This value can come from another set of algorithms, such as from an uncertainty analysis, or can simply be a "plugged" number based on expert judgment. Since PWR operational costs are well known, a zero contingency was assessed for this System 80+ case.

Figure 1 INPUT DATA Worksheet

	A	B	C	D	E	F
1						
2		WORKSHEET NAME: **INPUT DATA**				
3			Items in blue are inputs			
4		**Data from Designer**				
5		Plant description	**System 80+ PWR on existing NPP site**			
6		Site size	0	acres	not used for this case	
7		or	0.00	hectares		
8		Reactor Net Capacity	1300	Mwe		
9		Reactor Capacity factor	80.00%			
10						
11						
12		Plant economic life	40	years		
13		Years to construct (up to 5 yrs allowed)	5			
14		Type of spending profile during constr	S-curve			
15		% spent during year 1	10%			
16		% spent during year 2	25%			
17		% spent during year 3	30%			
18		% spent during year 4	25%			
19		% spent during year 5	10%			
20		(enter zeroes if constr yrs < 5)				
21		**EMWG Non-fuel Data**				
22						
23		Cost per acre for land	15000	$/acre	not used for this case	
24		Average craft labor rate	32	$/hr	not used for this case	
25		Financial environment	regulated as represented by lower discount rate, no taxes			
26		Real discount rate for IDC & amortiz	5.00%			
27		Estimated D&D cost	300	$M		
28		**Fuel Data from Designer:**				
29		Fuel cycle type	once-through			
30		Reactor Net Electric Power	1300	Mwe		
31		Reactor Type	System 80+ PWR on existing NPP site			
32		Reactor capacity factor (unadjusted)	80.00%	%		
33		Fuel Material	zirc-clad low-enriched UO2 pellets			
34		U-235 enrichment level (1st core ave)	2.64%	% U-235		
35		U-235 enrichment level (reload ave)	3.780%	% U-235		
36		Heavy metal mass of fuel assembly	0.426	MTHM		
37		Fuel Assemblies in Full Core	241			
38		Fuel Assemblies per Reload	107			
39		Average time between refuelings	1.5	yrs		
40						
41		**EMWG Fuel Cycle Data:**				
42		Enrichment plant tails assay	0.3000%	%U-235		
43		Enrichment level of feed	0.7110%	%U-235		
44		Life of plant	40	years		
45		Cost of uranium ore	12.00	$/lbU3O8		
46		or	31.20	$/KgU		
47		Cost of U3O8 to UF6 conversion	6.00	$/kgU		
48		Cost of Enrichment	100.00	$/SWU		
49		Cost of enr. Plt. Tails conv/disposal	0.00	$/kg DU		
50		Cost of Fabrication	180.00	$/kgHM		
51		Cost of once-through geol waste disp	1.00	$/MWh		
52		Cost of reprocessing	0	$/kgHM	not used for this case	
53		Contingency on fuel cost	0	%	not used for this case	
54		**Non-Fuel Operational Recurring Costs**	(Other formats may exist req mod to this table & results)			
55		On-site Staffing Cost	23.531	$M/yr		
56		Pensions and Benefits	6.286	$M/yr		
57		Consumables	18.636	$M/yr		
58		Repair costs	4.559	$M/yr		
59		Charges on working capital	0	$M/yr		
60		Purchased services & subcontracts	6.375	$M/yr		
61		Insurance premiums & taxes	7.04	$M/yr		
62		Regulatory fees	4.075	$M/yr		
63		Radioactive waste management	in purch service	$M/yr		
64		Other General and Administrative (G&A)	7.965	$M/yr		
65		Capital replacements	0	$M/yr		
66		Contingency on non-fuel O&M cost	0	$M/yr		
67						
68						

V. Worksheet Tab “EMWG COA and Capital”

This worksheet section of the overall Workbook contains both input and calculational features. Firstly, it allows for the organization of the total capitalized cost into the 69 possible categories as defined in the EMWG Code-of-accounts (COA) specified in the *Guidelines*. The entries can be entered by hand or can come from other off-line models or new reactor system-specific worksheets with cost-scaling equations. The data can also be entered at various levels of two-digit COA detail. It is possible to go as deep as entering labor-hours, labor rates, factory equipment, and commodity costs for each row. It is likely to be a long time; however, before that level of detail is available for Generation IV reactor systems. Even for the System 80+ system, only aggregated data was available for each 2-digit direct and indirect cost category (rows).

The only real calculation that is performed in this worksheet is summation of the rows in the appropriate subtotals. There are some row entries, however, that are calculated and come from other worksheets. Among these are:

- Interest during construction (Account 62): from “finance” worksheet
- First or initial core fuel load (Account 55): from “unit EU cost” workbook
- Contingencies (Accounts 19,29,39,49,59,69): from future algorithms or programs or are entered by hand.

The Total capitalized cost that is calculated is transferred to the “finance” worksheet, where amortization of this amount into level annual payments is calculated. Figure 2 below shows this Worksheet for the example problem.

			Jan 1987 to Jan 2001 escalation factor:	not used	"Burdened"Craft labor	not used	$/hr (Jan 2001 $)		
			Costs in $M						
Old EEDB Acct #	Mod IAEA Acct #	New EMWG Acct	Description	Factory eqt costs ($M)	Site labor hours (person-hrs)	Site labor cost ($M)	Site mat'l/commodity cost ($M)	Total Cost ($M)	Specific Cost ($/kw)
			System 80+ PWR on existing NPP site						
		1	**Capitalized Pre-construction Costs (subtotal)**					**$5.000**	4
		10 series							
20	20	11	Land and land rights					$5.000	
		12	Site permits	For this case these costs are imbedded in COSs below				$0.000	
		13	Plant licensing	For this case these costs are imbedded in COSs below				$0.000	
		14	Plant permits	For this case these costs are imbedded in COSs below				$0.000	
		15	Plant studies	For this case these costs are imbedded in COSs below				$0.000	
		16	Plant reports	For this case these costs are imbedded in COSs below				$0.000	
		17	Reserved for other activity as needed	For this case these costs are imbedded in COSs below				$0.000	
		18	Reserved for other activity as needed	For this case these costs are imbedded in COSs below				$0.000	
		19	Contingency on 11-18 above	imbedded below for in overall contingency for this case				$0.000	
	2	2	**Capitalized Direct Costs (subtotal)**	$0.000	0	$0.000	$0.000	**$1,249.600**	961
		20 series		For some systems, some of these costs may flow from other models with cost-scaling relations					
21	21	21	Buildings, Structures, & Improvements on Site	Data not available at Eqt/Labor/Commodity level				$338.600	
22	22	22	Reactor Plant equipment	Data not available at Eqt/Labor/Commodity level				$349.300	
23	23	23	Turbine/Generator Plant equipment	Data not available at Eqt/Labor/Commodity level				$331.400	
24	24	24	Electrical equipment	Data not available at Eqt/Labor/Commodity level				$96.600	
26	25	25	Water intake and heat rejection plant	Data not available at Eqt/Labor/Commodity level				$70.300	
25	26	26	Miscellaneous plant equipment	Data not available at Eqt/Labor/Commodity level				$63.400	
	27	27	Special materials	not applicable				$0.000	
	28	28	Simulator	in acct 22				$0.000	
		29	Direct Cost Contingency	imbedded below for in overall contingency for this case				$0.000	
	3	3	**Capitalized Support Services (Subtotal)**			$0.000		**$473.300**	364
		30 series				mostly labor			
92/95[JGD92]	30	31	Design Services at A/E Offices (home office)					$74.300	
92/95	31	32	PM/CM Services at A/E Offices (home office)	data at this level not available		in acct 31		$0.000	
941[JGD93]	32	33	Design services at plant site (field office)					$107.600	
92	33	34	PM/CM services at plant site (field office)			in acct 33		$0.000	
932[JGD91]	34	35	Construction supervision at plant site (field spvn)					$291.400	
91	35/38	36	Field indirect costs (rentals, temp facil, etc)			in acct 35		$0.000	
934	36	37	Plant commissioning services			in acct 35		$0.000	
934	37	38	Plant operation-demonstration run			in acct 35		$0.000	
		39	Contingency on 31-38 above	imbedded below in overall contingency for this case				$0.000	
	4	4	**Capitalized Operations costs (Subtotal)**					**$240.500**	185
		40 series	**[prior to commercial operation]**						
944	41	41	Staff recruitment and training			in acct 46		$0.000	
944		42	Staff housing facilities			in acct 46		$0.000	
		43	Staff salary-related costs			in acct 46		$0.000	
		44	Reserved					$0.000	
		45	Reserved					$0.000	
946	70	46	Other Owners' capital investment costs					$240.500	
		47	Reserved					$0.000	
		48	Reserved					$0.000	
		49	Contingency on 41-48 above	imbedded below in overall contingency for this case				$0.000	
		5	**Capitalized Supplementary Costs (subtotal)**					**$68.805**	53
		50 series							
	50	51	Shipping & transportation costs			in acct 35		$0.000	
943	51	52	Spare parts and supplies			in acct 26		$0.000	
942		53	Taxes			not applicable		$0.000	
942	53	54	Insurance			not applicable		$0.000	
		55	Reserved					$0.000	
		56	**First Fuel Load or First Core**	from fuel cycle model				$68.805	
		57	Reserved					$0.000	
	54	58	Reserved					$0.000	
	52	59	Contingency on 51-58 above	for this case the acct 56 conting is zero; other cont is handled below				$0.000	
		1 - 5 Sum							
		CONT	Total contingency:accts 19+29+39+49+59	input data for this case. May be calc offline using G. Rothwell's method.				**$294.500**	227
OVNT		OVNT-NO-F	Overnight cost without first fuel load					**$2,262.900**	1741
		OVNT-F	Overnight cost with first fuel load					**$2,331.705**	1794
		6	**Financial Costs (subtotal)**					**$408.885**	315
		60 series							
	60/71	61	Escalation			not applicable	for const $ calc	$0.000	
AFUDC	61/72	62	Interest during construction			calc from acct 68		$371.714	
	62	63	Fees/Royalties			in acct 46		$0.000	
		64						$0.000	
		65						$0.000	
		66						$0.000	
		67			This cont. may be calc			$0.000	
		68			from another model			$0.000	
		69	Contingency on 61-68	% of acct 62=	10.0%			$37.171	
					per G. Rothwell's method				
TCC		Accts10-60	**Total Capitalized Cost (TCIC)**					**$2,740.591**	**2108**

Figure 2 EMWG COA and Capital Cost Worksheet

VI. Worksheet Tab: "Finance: IDC and Amortization"

Interest during construction calculation. Interest during construction (IDC) is essentially the interest on the borrowed funds (loan) to design, construct, and start-up the reactor project. The first step is to subdivide the "overnight cost" (cell I-68) into year-by-year funding requirements up to commercial operation. (Note: the term "overnight" cost refers to the fact that this would be the capital cost of the reactor if it could be built "overnight" with essentially no time between expenditure of capital funds and the beginning of production revenues. In essence the interest on the "construction loan" would be zero and it would be necessary only to recover the "overnight" cost in the revenue stream.) For the System 80+ example the "overnight" reactor cost is $2332M.

The overnight cost is subdivided into yearly cash flows by use of the year-by-year spending fractions which come from the input table. These fractions must sum to 1.0 and define the shape of the cumulative spending pattern. For the example an S-curve pattern over 5 –years is assumed. Up to five years for design/construction/start-up are allowed. The fractions are multiplied by the overnight cost to calculated how much money (principal) must be borrowed each year. It is assumed that interest accrues at the end of each year, and that each years principal is not repaid with compounded interest until the end of the last year, i.e. immediately before commercial operation. (In the example the amount borrowed in year 1 must be repaid with 5-years worth of interest at the 5% discount rate. The amount borrowed in year 2 with 4-years worth, the amount in year 3 with 3-years worth etc.) The total of the accumulated interest for all five funding increments is the total interest during construction (IDC). For the example the IDC comes to $372M. There is also a provision to add "contingency" to the IDC. Any contingency would likely be due to schedule slippage which increases the interest costs ("time is money"). This contingency can be defined in cell F80 or it can be brought in from another model, such as one that analyzes schedule uncertainties. For the example a 10% contingency on the IDC brings the "financial cost" total up to $409M.

The total of the contingency-adjusted IDC ("total financial cost") and the "overnight cost" is the total capitalized cost. Note that the overnight cost includes the first core fuel plus any contingencies. For the example System 80+ this amount sums to $2741M. See Figure 3 below.

Amortization (capital recovery) calculation. The Total Capitalized Cost, which includes all relevant contingencies, adjusted IDC, and the first core, is the amount which is essentially "amortized" in a mortgage type loan over the life of the reactor. In the U.S. this would be similar to a situation where a homeowner gets a construction loan from a bank to build his residence. Before occupying the residence he "rolls over" the sum of the construction cost plus the interest on his construction loan into a new bank loan amortized over the time he expects to live in the residence.

For this simplified model the discount rate used for IDC ("construction loan") calculation is the same as that used for loan amortization. Another name for loan amortization in this case is capital recovery. Essentially the utility will pay back the total capitalized cost on a levelized annual basis out of electricity sales revenues. The revenues must also cover other costs such as reload fuel, operations, and the contributions to the D&D escrow fund.

The amortization formula in the Guidelines is used to calculate the % of the total capitalized cost that must be recovered each year over the facility life. This fraction is also called the fixed charge rate. For the System 80+ example 5.83% of the TCC must annually be paid back for all 40 years of operations or ~$160M/yr in constant dollars. This is essentially the annual "mortgage payment" which repays interest plus principal on the project.

One can now also calculate the capital contribution to the cost of electricity by distributing the annual payment over the number of kilowatt-hours generated annually by the reactor. The capacity factor is used to convert the design capacity of the reactor (1300 MW net) to kilowatt-hrs actually produced. For the example:

9.11E9	= 0.8	*	8760	*	1000	*	1300
kwh/yr	Cap factor		hrs/yr		kw/MW		MW

Note that the adjusted capacity factor should be used, i.e. the one calculated after the "performance discount" contingency fraction multiplier is applied. For the System 80+ no performance discount is applied against the initial 80% projected capacity factor.

If the $160M/yr of capital recovery is distributed over the 9.11 billion kwh generated per year, a unit cost of $17.5/MWh or 17.5 mills/kWh results. This is the capital component of the LUEC, and for any reactor system is likely to be the largest component compared to the operations, D&D, and fuel components. Calculation of these latter three components is now considered.

Interest during Construction Calculation			(S-curve profile must be entered by hand)						
Number of years for Construction:	5	yrs	yr	yr	yr	yr	yr		
S-curve			1	2	3	4	5	tot	
Spending profile for	5	years:	10%	25%	30%	25%	10%	100%	
								check sum	
Construction Loan Amt (O'night cost)	$2,332	$M	$233.17	$582.93	$699.51	$582.93	$233.17	$2,331.71	
& spending profile ($ borrowed at beg of yr)									
								total	
Annual interest at real disc rate of	5.00%		$64.42	$125.62	$110.26	$59.75	$11.66	$371.71	
Interest during construction	**$371.71**	**M**							

Amortization of Capital into Unit Cost (Capital portion of LUEC)									
Real Discount rate	5.00%							this model mills/kwh	JGD model mills/kwh
							Capital	17.53	16.78
Operating/economic life of Plant	40	yrs					Fuel	4.03	4.03
							O&M	8.61	8.61
Capacity factor	80.00%						D&D	0.27	0.24
								30.44	29.66
Contingency on capacity factor	0.00%	(can use G. Rothwell's method to calculate)							for 5% DR
Adjusted capacity factor	80.00%								
Annual power production (adjusted)	9.11E+09	kwh/yr							
Amount to be amortized (TCIC)	2740.5907	$M							
Fixed charge rate	0.0582782	per yr							
Annual capital recovery	$159.72	$M/yr							
Capital component of LUEC	**0.0175**	**$/kwh**							
	17.5	**$/MWh or mills/kwh**							

Figure 3 Finance: IDC and Amortization Worksheet

VII. “Unit Equivalent Enriched Uranium Cost” Worksheets (Front End Fuel Cycle Steps)

These two worksheets are basically the same set of algorithms, with UNIT EQUIV.EU.COST_FC calculating the cost of the first core (FC) [Fig 4] or “initial core” , and the other worksheet EQUIV.EU.COST_RL [Fig 5] calculating the cost of each reload fuel batch. The data required comes from the INPUT DATA worksheet, which passes the fuel designer’s requirements (fuel assembly mass, required U-235 enrichment. And number of assemblies) and the economic evaluator’s inputs (unit cost of SWU, ore, etc and the transaction tails assay) to these two worksheets. The values for these input are repeated in red print in the two worksheets.

The worksheet algorithms first use material and SWU balances to calculate the amount of feed U and separative work (SWU) to make the amount of fuel of the desired enrichment. The requirements for ore, conversion, SWUs, fuel fabrication, and DUF6 conversion/disposal are calculated. The total amounts of these services/materials required to produce 1 kg of U fuel is then calculated. The worksheet also picks up the unit costs of these services from the INPUT DATA worksheet and these inputs are also printed in red. By multiplying unit costs (or prices) times the amounts of each required, the overall cost per kgU for all front end fuel cycle steps is calculated.

This unit cost can be multiplied by the mass of an assembly (in KgU) and the number of assemblies per charge to calculate the overall front-end fuel cycle cost of a reload batch and the initial core. A table showing the percentage breakdown of the front-end fuel cycle cost among all the services and materials is printed for each. This data is then transferred to the worksheet FUEL CYCLE ECONOMIC CALC to complete the calculation.

Uranium Fuel Costing Bases: Full Init Core	System 80+ PWR on existing NPP site			
(no losses)				
U-Ore Cost (2002$/lbU3O8)	12		(in $/KgU)	31.20
U3O8 to UF6 Conv Cost($/KgU)	6			
Tails Assay (w/o U-235)	0.3		(Value Fct.)	5.7713017
Fab Cost,UF6 to metal or assy's ($/KgU)	180	$/kgU		
Ore + Conversion Cost ($/KgU)	37.20			
Desired Prod. Enrichm't(%U-235)	2.64		(Value Fct.)	3.4171533
F/P ratio for enrichment	5.693430657			
W/P ratio for calc of tails gen	4.693430657			
Feed Assay to Enr Plt(%U-235)	0.711		(Value Fct.)	4.8688834
Total SWU/KgU product	2.783707485			
SWU price	100	$/SWU		
Tails conversion/disposal price	0	$/kg DU		
SWU component of product cost	278	$/kgU		
Tails conversion/disp per unit of EU	0.00	$/kgU		
Comp prod cost (ore,conv,fab,tails disp)	392	$/kgU		
Total EU cost per kg U	670	$/kgU		
Kg U-235 per fuel assembly	11.2			
Kg U per driver or fuel assy	426		enr-U in core	102666 kgU
Fuel assy's per full core	241			
Cost of EU in full core(comm'l basis)	6.88E+01	$M		

Commercial cost basis:	total core $		component %	$/kgEU
Ore component of core cost	18.239	$M	26.51%	178
conversion or blend comp	3.507	$M	5.10%	34
SWU component	28.579	$M	41.54%	278
Tails conv/disp comp	0.000	$M	0.00%	0
Fab(EUF6 to assy) comp	18.480	$M	26.86%	180
	--------------------		--------------------	-----
Cost of first full core if comm'l	68.805	$M	100.00%	670

Metric tons of ore U3O8 req'd	584.5	MT U3O8

Figure 4 Initial Core “Equivalent U Cost” Worksheet

Uranium Fuel Costing Bases: Reloads	System 80+ PWR on existing NPP site			
(no losses)				
U-Ore Cost (2002$/lbU3O8)	12		(in $/KgU)	31.20
U3O8 to UF6 Conv Cost($/KgU)	6			
Tails Assay (w/o U-235)	0.3		(Value Fct.)	5.7713017
Fab Cost,UF6 to metal or assy's ($/KgU)	180	$/kgU		
Ore + Conversion Cost ($/KgU)	37.20			
Desired RL Prod. Enrichm't (%U-235)	3.78		(Value Fct.)	2.9922026
F/P ratio for enrichment	8.467153285			
W/P ratio	7.467153285			
Feed Assay to Enr Plt(%U-235)	0.711		(Value Fct.)	4.8688834
Total SWU/KgU product	4.861814709			
SWU price	100	$/SWU		
Tails conversion/disposal price	0	$/kg DU		
SWU component of product cost	486	$/kgU		
Enrichment unit (SWU) Cost	100.00	$/SWU		
Tails conversion/disp per unit of EU	0.00	$/kg U		
Comp prod cost (ore,conv,fab,tails disp)	495	$/kgU		
Total EU cost per kg U	981	$/kgU		
Kg U-235 per fuel assembly	16.1			
Kg U per driver or fuel assy	426		enr-U in core	45582 kgU
Fuel assy's per reload	107			
Cost of EU in reload (comm'l basis)	4.47E+01	$M		

Commercial cost basis:	total core $		component %	$/kgEU
Ore component of reload cost	12.043	$M	26.93%	264
conversion or blend comp	2.316	$M	5.18%	51
SWU component	22.161	$M	49.55%	486
Tails conversion/disposal	0.000	$M	0.00%	0
Fab(EUF6 to assy) comp	8.205	$M	18.35%	180
	--------------------		---------------------	-----
Cost of reload partial core	44.725	$M	100.00%	981

Metric tons of ore U3O8 req'd	385.9	MT U3O8

Figure 5   Reload "Equivalent U Cost" Worksheet

VII. WORKSHEET: FUEL CYCLE ECONOMIC CALCULATION

This section calculates the total cost of nuclear fuel for both the first core and reloads. For the reloads it also calculates the fuel contribution to the LUEC. (Note that the capital component of the LUEC includes the initial fuel core cost and amortization.)

Initial Core Cost: This total cost is calculated by merely summing the costs for the front end fuel cycle material/service components (ore, SWU, etc.) which passed from Worksheet EQUIV.FUEL.CYC_FC. This cost for all assemblies in the initial core is designated in the EMWG COA as 2-digit account 61. The value is passed on to Worksheet EMWG COA & CAPITAL. For the System 80+ example the total first core cost (241 assemblies) is $68.8M. The cost for spent fuel disposal is not included in this account. Since spent fuel disposal is paid on a per kilowatt-hour generated basis, its cost must be relegated to the annual (reload) fuel costs. It should be noted that the spent fuel disposal cost is not affected by the amount of fuel consumed or the timing of fuel purchased. It only depends on the power production timing, which for this model example is assumed to be level over the plant 40 yr operating life.

Annualized Reload Fuel Costs: This module is somewhat more complex due to the fact that the reactor may be reloaded with fuel on non-1 year cycles and that first core fuel is likely to reside in the reactor well after the first year. In any case we want to treat reload fuel as if it is bought every year of reactor operation. This levelization is necessary in order to calculate the fuel contribution to the LUEC.

The number of “full reloads” required over the plant life must be calculated. Adjustment must be made for the fact that both initial core and reload fuel may remain in the reactor for multiple cycles, and in the last few years of reactor operations, partial rather than full reloads may be required. Adjustment must also be made for the initial core and the fact that it has assemblies which will stay in the reactor even after the first reload is charged. The number of “equivalent full” reloads is first calculated by dividing the number of years of reactor ops by the cycle time. For the example System 80+ and its 40 year life and 1.5 year cycle, simple division says that 26.6 reloads are required. This must be adjusted; however, to avoid double counting assemblies. This adjustment is made by taking the ratio of the number of initial core assemblies and dividing it by the number in a full reload (241 / 107 = 2.25 for the sample case), integerizing this value, and subtracting it from the number of reloads calculated above. (For the example, 24.6 = 26.6 – INT (2.25))

Now that we know the number of “equivalent full reloads” needed for the plant life, and the cost of the reload fuel cycle front-end components (ore, SWU, etc from EQUIV.FUEL.CYC_RL); we can annualize the HM mass and cost of all reloads purchased over the plant life (40 years for the example). If this annual reload cost (front-end costs only) is divided by the annual electricity production, the LUEC component for fuel can be calculated. For U.S. reactors the waste disposal fee of 1 mill/kwh must be added to this value.

	Initial Core (to be included as part of Overnight Cost of Reactor):		
Account #	System 80+	**Cost in 2001$M**	
61	First Core Total (sub COAs below incl transportation to provider)	$68.81	
611	Ore cost	$18.24	
612	U3O8 to UF6 Conversion Cost	$3.51	
613	Enrichment (SWU) Cost	$28.58	
614	Fabrication Cost	$18.48	
615	DUF6 Tails Conversion/disposal cost	$0.00	
	Simplifying assumptions: no U losses, no spare fuel assy's, no lead or lag times		
	Calculations for reloads:		
	System 80+	1300	Mwe net
	Years of Reactor operations:	40	yrs
	Time between refuelings:	1.5	yrs
	Number of "equiv full" refuelings over plant operational life (# of full reload batches)	24.66666667	
	[acct's for no double count of 1st core load in cyc 1 and no full rl in last cycs of ops]		
	Annualized # of reloads	0.62	
	Annual electricity production (using adjusted capacity factor)	9.11E+09	kwh/yr
	@ Capacity factor (adjusted for contingency) with 8760 hr/yr	80.00%	
	Mass of a reload	45582	KgHM
	Average Annual enriched U requirement	28108.9	kgHM or EU per yr
	Ratio of assy's in 1st core to # of assy's in reload	2.25	
	Simplifying assumptions: no U losses, no spare fuel assy's		
	No lead/lag times		
Account #	Activity	2001$M per year	$/MWh or mills/kwh
8	Annualized reload costs		
84	**Front-end Fuel cycle**	**$27.58**	**3.027**
841	Annual average ore cost	$7.43	0.815
842	Annual average conversion cost	$1.43	0.157
843	Annual average enrichment cost	$13.67	1.500
844	Annual average fuel fabrication cost	$5.06	0.555
845	Annual average tails conv/disp cost	$0.00	0.000
86	**Back-end Fuel Cycle**	**$9.11**	**1.000**
861	Annual ave reprocessing cost	n/a	
862	Credits for U, Pu, etc	n/a	
863	Final disposal of assemblies	$9.11	1.000
864	Final disposal of wastes (from reprocessing)	n/a	
Total FC (84+86)		**$36.69**	**4.027**
89	Contingency on above accts 84 and 86	$0.00	$0.00
	Total Annualized Fuel Cycle	**$36.69**	**4.027**

Figure 6 "Fuel Cycle Economic Calculation" Worksheet

IX. OPERATIONS and DECOMMISSIONING Worksheet

Recurring and levelized O&M costs: At this stage of development the operations cost model is very simple, in that annual costs (account 7X values) for the various O&M categories are entered in the INPUT DATA worksheet, passed to this worksheet, summed, and distributed over the years of power production. For the System 80+ example, these “recurring” or “levelized” costs sum to $78.5M annually and are assumed the same for all 40 years of the plant’s life. If this value is divided by the annual electricity production, a levelized operations component of the LUEC is calculated at $8.61/MWh or 8.61mills/kWh.

D&D Costs: The lump sum constant dollar cost to decontaminate and decommission the nuclear plant is passed from the INPUT DATA worksheet. This is the sum needed at the end of life. A sinking fund (essentially an escrow account) is used to accumulate this needed sum over the years of plant operation. [The sinking fund formula in the Guidelines calculates the annual payments needed to accumulate the lump sum cost at end-of-life.]   For the System 80+ example $300M is needed at EOL. At the discount rate (5%) $2.48M annually is needed over 40 years to accumulate this sum. The D&D component of the LUEC can be calculated by dividing this annual amount by the annual power production. For the example the D&D contribution to the LUEC is 0.273 $/MWh or 0.273mills/kWh.

OPERATIONS & D&D WORKSHEET			
7	**OPERATIONS COST CATEGORY**		
70 series	input data in blue		
71+72	On-site Staffing Cost (71: non-mgt 72: mgt)	23.531	$M/yr
73	Pensions and Benefits	6.286	$M/yr
76, 74	Consumables	18.636	$M/yr
75	Repair costs including spare parts	4.559	$M/yr
?	Charges on working capital	0	$M/yr
84+ ?	Purchased services including refueling crews	6.375	$M/yr
78	Insurance premiums & taxes	7.04	$M/yr
?	Regulatory fees	4.075	$M/yr
?	Radioactive waste management (non-spent fuel)	in purch service	$M/yr
?	Other General and Administrative (G&A)	7.965	$M/yr
77	Capital replacements/upgrades (levelized)	0	$M/yr
79	Contingency on O&M	0	$M/yr
7	**Total**	**78.467**	**$M/yr**
	Annualized D&D cost per kwh	0.00861	$/kwh
		8.613	mills/kwh
			or $/Mwh
58	**Decontamination and Decommissioning Cost (D&D)**	300	$M
	(annualized rather than capitalized)		
	Sinking fund interest	5.00%	/yr
	Sinking fund factor	0.00828	/yr
		40.0	yrs
	Annualized D&D	2.483	$M/yr
	Annualized D&D cost per kwh	0.00027	$/kwh
		0.273	mills/kwh
			or $/Mwh

Figure 7 Operations and D&D Worksheet

X. LUEC SUMMARY Worksheet

This worksheet (Table 1 below) merely picks up the annualized cost and LUEC component results from the proper worksheets and sums them to obtain the overall busbar LUEC. Note that this is a busbar cost, and that no electricity distribution costs are included in this sum.

Table 1 Summary of Model results for System 80+ Example

Summary of Model Results		
Case: System 80+ PWR on existing NPP site		
	Annualized Cost in $M/yr	Mills/kwh or $/MWh
Capital Cost incl Financing	$159.7	17.53
Operations Cost	$78.5	8.61
Fuel Cycle Cost	$36.7	4.03
D&D Cost	$2.5	0.27
Totals	$277.4	**30.44**

XI. Model Validation

Comparison of Results of this Model based on "More Complex" model based on *1993 Cost Estimating Guidelines:*

A 1999 EXCEL-based model developed by Mr. Jerry Delene, now retired from ORNL, is based on the 1993 Cost Estimating Guidelines applicable to U.S. Gen III or Gen III+ reactor systems. This model is considerably more complex in its input requirements and is based on a regulated U.S.utility financial environment typical of pre-deregulation electrical powerplants This '1999 model" case included the following features and assumptions:

- Federal income tax and depreciation rules specific to the U.S.
- Local property tax typical of U.S. locations

- 3% inflation and the use of nominal dollar costing
- Equity and debt financing
- An allowance for capital replacements
- Lag and lead times for the purchase of fuel cycle services and materials
- Detailed fuel material balance data (first core and reloads)

This model was deemed too complex and "U.S.-specific" for the "international" type model needed by the EMWG to assess Gen IV nuclear reactor systems. It was also not amenable to being used within a design/optimization package or compatible with cost-scaling algorithms, This is especially true for reactor systems for which cost data does not exist at the same level of detail as for Gen III systems. For this reason the new EMWG EXCEL model ("2004 model") was developed with the following simplifications as discussed earlier:

- No built-in depreciation or tax algorithms
- Zero real escalation (everything in constant dollars)
- One discount rate to cover construction financing, capital amortization, and D&D fund accumulation
- Annualization of all costs, including capital recovery using a constant dollar fixed charge rate, O&M costs, a D&D escrow fund, and purchase of fuel.
- Inclusion of the first core in the Total Capitalized Cost

In order to validate the new EMWG model using the System 80+ reactor example, it was decided to run the "old" model with escalation, tax rates, lag times and lead times, etc. all zeroed out. Other input parameters, such as fuel cycle unit prices (ore, SWUs, etc), subsystem direct and indirect costs, annual O&M costs, etc were set the same for both models. The models were both run with a 5% real discount rate. **Table 2** shows the breakout of the unit cost of electricity obtained from each model.

Table 2 Comparison of Two Power Generation Cost Models

POWER GENERATION COST, mills/kWh or $/MWh		
1300 Mwe Sys 80+PWR using 5% real disc rate	1993 model with financial simplifications	new, simpler 2004 EMWG model
Capital Investment	**16.78**	**17.53**
O & M Costs	**8.61**	**8.61**
Fuel Costs	**4.03**	**4.03**
ore (U3O8)	0.81	0.81
conversion	0.16	0.16
enrichment	1.47	1.50
fabrication	0.59	0.56
DUF6 tails conversion & disposal	0.00	0.00
spent fuel disposal	1.00	1.00
Decommissioning Cost	**0.24**	**0.27**
Total	**29.66**	**30.44**

The closeness of the results (within 2.7%) appears to validate that the simpler EMWG model formulation allows close approximation to the formulation present in the more complex model under nearly identical input conditions. This fact should allow users a high level of confidence in the EMWG model's calculational capability.

The lack of tax algorithms, etc., from the EMWG model, however, raises another issue, i.e. that of realism. Taxes, equity financing, etc all have a "cost" which is reflected in the capital component of the cost of electricity. In order to investigate the incremental costs of these institutional/macroeconomic factors, the "1999" model was run with all the taxes, etc included for the 1300 MWe PWR case. The capital component for this case was $30.58/MWh and the total LUEC (levelized unit cost of electricity) was $43.46/MWh. **Table 3** shows the effect of then selectively removing these various macroeconomic factors one-at-a-time. At the end of the process, using simple debt financing and a real discount rate of 5%, a $16.78/MWh capital component is obtained. What this tells the analyst, is that for U.S. regulated utility type scenarios, one should use a higher discount rate in the simple EMWG model to "simulate" social and financial costs and risks that exist in many developed countries. If the EMWG model for the 1300 MWe PWR is run at a 9% real discount rate, a capital cost component of $30.57 results, which is close to the result of $30.58 obtained with the "1999" model for the regulated utility U.S. case. **Table 3** shows the conditions under which this "1999" model was run. The conclusion which can be drawn is that judicious selection of the real discount rate can be used to reflect the effect of financial and socioeconomic factors at various possible international locations. Higher discount rates can also be used to account for the risk associated with projects built in a deregulated environment or under "merchant plant" type scenarios.

Table 3 Financial Simplification Sensitivity Study on a More Complex Model

Effects of Financial Simplifications from 1993 "Guidelines" Model for U.S Regulated Utility Nuclear Plant		
Cumulative changes:	**Capital component of levelized cost (mills/kwh or $/Mwh)**	**Comments**
Base	30.58	Regulated environment--- 3% inflation; financing: 47% debt @ 7.4% nom; 47% equity @12% nom 6%; Pref Eq @ 6.9% nom; 38.9% Fed Tax rate; 1.5% local tax rate; 0.5% interim repl rate. 1st core not in capital cost
Remove Federal Tax	27.32	
Remove Local Tax	23.96	
Remove interim replacement rate	22.45	Replacements are moved to O&M costs
Remove inflation component	21.92	Small change because const $ used for all calc
Use all debt financing at 5% real	17.81	
Change economic life to 40 years	16.78	
Other components of electicity unit cost add to 12.88$/MWh, hence the total electicity cost above starts at 43.46$/MWh (base) and ends up at 29.66$/MWh.		Use of a 9% real discount rate for 40 yr economic life would give capital component of 30.57 $/MWh. Thus use of a 9% real discount rate in the 2004 simple model can be a stand in for a National Economy with a tax and finance structure similar to the US "regulated utility" case.

XII. Use of the EMWG Model to Date

The model is presently being used in two applications. The first is to calculate cost figures of merit for gas-cooled reactors that might be used for hydrogen production. For this example it may be necessary to make a sight modification to calculate the levelized unit heat cost (LUHC) rather than the LEUC.

The model is also being used by the AFCI Economic Benefits Working Group to calculate levelized unit costs of production (such as $/kgHeavyMetal) for fuel cycle facilities. Again, some minor changes to figures-of-merit and nomenclature are needed.

Again, the use of MS EXCEL and the simplicity of the economic algorithms allow great flexibility in the use of this model.